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FUEL CELL BENEFIT ANALYSIS

by

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ARGONNE NATIONAL LABORATORY

ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

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June 1976

Prepared for the
Division of Conservation Research and Technology
U. S. Energy Research and Development Administration

PREFACE

This study was accomplished by a small group of dedicated people in a two-month time period. The effort was considered necessary as a "check" against a much more complete study, done at United Technologies.

The savings reflected in this report, although very significant, are not as high as those claimed by United Technologies. There are three main reasons for this: a) there was no time for Argonne to do the necessary "system study" needed to calculate the savings in spinning reserve applications; b) the "old plant replacement" market assumption was different in the two studies; and c) the "on-site" (40 kw) market and application were not treated in depth by Argonne due to time constraints.

The results of this and other studies strongly indicate that fuel cell systems have the potential of saving 275,000 barrels of oil per day by 1985 and over $1 billion per year in lower electric costs in the same time period.

Lloyd R. Lawrence, Jr.
Program Manager
Cycles and Components Branch
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and Technology
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ABSTRACT

A study was performed to evaluate the potential benefits resulting from the commercialization of first-generation fuel cells in the early 1980s. Utilization of fuel cells was assessed for electric generation, integrated energy systems, combined production of electricity and industrial process steam, and export markets. The electric utility market was further divided into new capacity for privately-owned utilities, rural electric cooperatives, and for replacement of obsolete units. In addition, an evaluation of the effect of a different growth rate for electricity demand was performed. On the basis of these evaluations, it was found that there would be substantial savings of energy and money, as well as substantial increases in exports, if first-generation fuel cells were brought to market in the early 1980s.

EXECUTIVE SUMMARY

Fuel cell technology has been developed to the point where efficient and practical generators can be introduced into the marketplace by 1980, but only if government support is available. The salient features of these generators are high efficiency, highly desirable environmental characteristics, flexibility of operation, availability in essentially any size, rapid installation, remote dispatch, and an ability to recover waste heat without any loss in efficiency. Fuel cells are quite versatile and can be used for electric utility operation, integrated energy systems, and to provide industrial process heat and electricity. They also possess a substantial export potential. Benefits from government support of fuel cells, based upon economic competitiveness, have been estimated as follows:

Range of Fuel Cell Installation,
1985 and 1990

1985	Low	Base	High
Mwe's installed	10,300	17,400	33,800
Associated Energy Savings (bbl oil/day)	95,000	174,000	279,000
Value of units exported (cumulative, in billions of dollars)	3.1	3.6	9.3
1990			
Mwe's installed	23,200	38,200	83,300
Associated Energy Savings (bbl oil/day)	228,000	380,000	562,000
Value of units exported (cumulative, in billions of dollars)	6.2	7.4	18.6

The above energy savings assume improvements in competing technologies. Compared to present technologies energy savings would in the base case be equivalent to 228,000 bbl of oil/day in 1985 and 494,000 in 1990. The discounted present value, at 10%, of dollars saved by fuel cells in the Northeast region, base case, and of exports to 1990 (assuming net exports are half of total exports) exceed $1,500,000,000 (in 1975 dollars).

Based upon these findings, we feel that government support of fuel cell development is appropriate.

INTRODUCTION

The purpose of this study is to evaluate the potential benefits resulting from the commercialization of first-generation fuel cells in the 1980s. To facilitate this goal, the report is divided into six sections: (I) a historical overview of fuel cells and the fuel cell program, (II) presentation of first-generation fuel cell characteristics, (III) fuel cell applications, (IV) laying out the ground rules for the benefit analysis, (V) an attempt to estimate benefits parametrically on an individual application basis, and (VI) an integration of results and conclusions.

I. HISTORICAL OVERVIEW OF FUEL CELLS AND PROGRAM

The history of fuel cells can be traced back to the experiments in 1839 by Sir William Grove, but it was not until the U.S. space program in the 1960s required a highly-efficient, reliable electrical generator of very high energy density that fuel cells were put to practical use. The research community, fostered by the space program, naturally foresaw the terrestrial application of fuel cells, but the level of capital expenditure and effort required to develop fuel cell generators using carbonaceous fuels discouraged all but one or two companies from significant development programs. Moreover, during the late sixties and early seventies, the current pressing need for energy independence and more efficient and pollution-free use of energy resources was not as clearly and generally recognized as it is now. Fuel cell development was continued, however, by a few organizations, most notably, United Technologies Corporation. Thus, the option of bringing the benefits of fuel cells to bear on energy problems remains open. Exercising this option will require federal support, and this study addresses potential benefits from such support.

II. FUEL CELL CHARACTERISTICS

There are a great variety of possible fuel cell types, but this study is concerned only with the first-generation, acid-electrolyte systems. It is possible to begin commercial use of generators of this type in the late 1970s with appropriate government support. Appendix I contains descriptions of other promising fuel cell types. Note that a portion of the benefit of first-generation fuel cell commercialization is embodied in its effect on these more advanced types.

A. *Operating Characteristics*

The acid-electrolyte fuel cells operate on gaseous or light liquid-hydrocarbon fuels with good efficiency and essentially no adverse environmental effects. They are highly flexible in response to changing loads, and can be rapidly installed in sizes from 40 kw on up. The target specifications of the United Technologies FCG-1 system are as follows:

Rating*†	26 Mw	
Heat rate (end of life)*	9000 Btu/kw-hr @ 6-20 Mw 9300 Btu/kw-hr @ 26 Mw	
Lifetime*	40,000 hrs	
Cooling*	Dry air or water	
Water required*	None	
Noise*	Acceptable in residential area	
Fuel*✣	Straight run naphtha or gas	
Emissions ($lb/10^6$ Btu heat input)	Fuel cell	Federal standards for gas-fired central station
Particulates**††	2.9×10^{-6}	2.9×10^{-1}
NOX**††	$1.3\text{-}1.8 \times 10^{-2}$	2×10^{-1}
SO2**✣✣	2.3×10^{-5}	8×10^{-1}
Cost***	$200-300/kw	
Operator requirements*	Remote dispatch	
Startup time*	4-6 hr	
Response to load change*	Very rapid (0.1 sec or less)	
Usable reject heat*	24% of fuel energy at maximum temperature of 165°C and 33% at temperature below 100°C	

*UTC specification.

†Composed entirely of independent 4.8-Mw modules. It is possible to have a module size as low as 40 kw without sacrificing performance characteristics.

✣Can be extended to clean coal gas, methanol, or light aliphatic liquids with minimum difficulty.

**York Research Corp., Y-7309, (April 1970).

††Federal standards as of 8/17/71.

✣✣For oil-fired central station--there is no requirement for gas-fired central station.

***Author's estimate, installed cost in 1975 dollars.

B. *Environmental and Siting Characteristics*

The environmental characteristics of fuel cells make them well suited to nearly any location. These attributes are of great value in such applications as replacement of urban plants and in environmentally sensitive areas like Southern California. They are also essential if the fuel cells are to operate so as to make use of reject heat, since competing technologies (e.g., gas turbines) are less attractive environmentally. (This application requires siting at the location where the heat is to be used.) Modules of 40-kw and 4.8-Mw size are being developed for initial marketing. Inasmuch as cost and efficiency are relatively insensitive to size in this range and above, intervening sizes also can be manufactured if demand warrants.

C. *Response to Varying Load*

For certain applications, it is desirable to provide a rapidly varying output of power to match load requirements. The phosphoric acid systems being developed can match a demand that varies by more than half their rated output within 0.1 sec. The efficiency of fuel cells improves slightly as power output is reduced from 100 to about 25% of rated load. Other generating devices lose efficiency to a greater or lesser degree at part load. For example, the simple-cycle gas turbine responds well to varying load but loses efficiency rapidly at partial output. The combined-cycle power plant retains efficiency rather well down to around 50% of rated output, but only if a period on the order of several hours is available to change from 100 to 50% output and back. One point to note is that fuel cell generators require about 4 to 6 hours for warmup to operating temperature. The implication of this point is that fuel cells would be "idled" at about 15% of rated power output, which achieves the same efficiency as at rated power, thus providing some power at all times.

D. *Siting and Installation*

Because of the desirable environmental characteristics of fuel cells, a wide variety of sites can be used. No cooling water is required, so all that is needed is a concrete pad and an output-power-line connection. The system is designed to be truck-transportable and to require minimum installation labor.

E. Operation and Maintenance

The 26-Mw, fuel cell generator is designed for remote dispatch; no operators are required. Routine maintenance can be done by a traveling crew. Periodic replacement of zinc oxide, sulfur traps in the fuel processor, and lubrication of blowers and pumps are in this category. The fuel cell modules must be replaced periodically.

F. Waste Heat

If an application (such as heating and air conditioning or generation of low-pressure steam) can be found for the exhaust heat of the fuel cell system, an additional quarter of the fuel energy (above the electrical output) is available as heat from 230 to 330°F and still another third as lower temperature heat. Again, their favorable environmental characteristics facilitate the use of fuel cells for waste heat recovery or in integrated energy systems.

III. AREAS OF APPLICATION

A. Electric Utility Uses

Fuel cells are clearly very well suited to peaking and intermediate uses in electric utilities, particularly where high efficiency and freedom from adverse environmental effects are desirable. Table 1 summarizes costs and efficiencies projected for peaking turbines, coal, and oil-fired intermediate generators, combined cycles, and fuel cells.

B. Heat Recovery and Integrated Energy Systems Applications

Two factors make fuel cells ideally suited to these applications: their benign environmental characteristics, and their availability in appropriate sizes. As stated earlier, fuel cell exhaust is essentially free of SO2, NOX, and particulates, and the noise levels are acceptable. Fuel cells have been installed in apartment buildings in sizes as small as 12.5 kw, and improved 40-kw units are being tested. Small (40-kw) units are somewhat (50%) more expensive than large (Mw-size) generators, but escalation of cost in small sizes is not nearly as great as with gas turbines, for example.

Table 1. Operating Characteristics and Capital Costs for Future Generating Units[a]

Unit Type	Size (Mw)	Lead Time (yr)	Installed Costs ($/kw)	Operating & Maintenance Cost: Fixed ($/kw yr)	Operating & Maintenance Cost: Variable (mills/kw-hr)	Heat Rate (Btu/kw-hr)[b]	Outage Rate (%)
Coal (Base)	600-1500	6	500	4.0	1.0	10,200	28.5
Oil (Base)	600-1500	5	330	3.6	.35	9,800	28.5
Oil (Int.)	400-600	5	300	3.2	.2	11,300	25
Combined Cycle	150-250	3	210	.9	3.7	9,000	30
Gas Turbine	50-200	2	140	.26	5.0	12,000[b] 13,000[b]	23
Fuel Cell	26	2	(200-300)	.26	3.0	9,000	8

[a]Approximately 1987. Operating characteristics are those expected and not design conditions. These are authors' estimates based upon the current literature.

[b]Depending on whether the utility faces a winter or summer peak.

IV. *ASSUMPTIONS*

As far as possible, this study will compare alternatives providing the same amount of energy. This analytical form is consistent with Steiner's theoretical conclusions, "If the list of services is the same, the benefits will be equal. In this case, benefit measuring is totally unnecessary and comparative cost provides necessary and sufficient conditions for choice."*

In evaluating fuel cell potential, a number of assumptions are made. These are: that the scope of this study does not extend beyond 1990, that the fuel cell must compete with the most likely alternative, and that initial market penetration will be in those areas most favorable to fuel cells.

V. *BENEFIT ANALYSIS*

The rate of introduction of fuel cells is highly dependent on the level of government funding. Therefore, two scenarios were evaluated: (1) with no government funding and (2) with large-scale funding to bring fuel cells to commercial realization as soon as possible. The first-case benefits are easy to evaluate as there are none; without some level of government support, it is extremely doubtful that fuel cells will become commercially viable. In case two, the fifty-six 26-Mw units on tentative order would be delivered by 1981 and in 1981 subsequent units would be available for purchase. Large-scale funding also moves forward the introduction of second-generation fuel cells to some time in the mid to late 1980s. Consequently, the benefit analysis is done only for case two in which there is government involvement.

Utility Applications

Carrying out this analysis involves the following assumptions about the utility market:

1. That oil is a permissible fuel, and that the natural gas is either (a) unavailable or (b) available at a premium price compared to oil.

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*P. O. Steiner, *The Role of Alternative Cost in Project Design and Selection*. Quarterly J. of Econ., *79*, p. 429 (1957).

2. That the growth rate of capacity additions for 1976 to 1990 is about 5% per year, with capacities for specific years being:

Table 2. National Electric Generating Capacity

Year	Capacity Mw in Thousands
1975	509.4
1980	631.0
1985	751.1
1990	967.9

Source: Temple, Barker, and Sloane, Inc., *The Economic Impact of EPA's Air and Water Regulations on the Electric Utility Industry*, preliminary draft, Part I, p. II-18, (Nov 1975). (This projection is very close to the latest by Electrical World, p. 46, Sept. 15, 1975 issue.)

This is considerably below the historic growth rate of 7%/yr for four reasons: (1) lower population growth rates, (2) rising or constant real prices as opposed to declining real prices, (3) the impact of changes in the rate structure such as the elimination of declining rate blocks, and (4) the impact of conservation efforts by consumers (see Appendix II for an evaluation of the effect of a higher electric capacity growth rate on demand for fuel cells).

3. That the capacity level of peakers (internal combustion and gas turbine generating units) will be as follows:

Table 3. Peaker Capacity

Year	Capacity Mw in Thousands
1975	44.8
1980	52.0
1985	64.1
1990	85.2

Source: *Ibid.* (Table 2)

The replacement and new capacity additions for the decade of the 1980s will be:

Table 4. Peaker Capacity Additions - New and Replacement

Period	Replacement Capacity (Mw in Thousands)	Added Capacity (Mw in Thousands)
1981-85	2.8	12.1
1986-90	3.7	21.1

Source: *Ibid.* (Table 2), pp. II 18-27.

The breakdown by type of replacement capacity is assumed equivalent to that existing in 1974, 11.5% internal combustion and 88.5% gas turbines,* while for added capacity, the internal combustion portion is about 3.5%.†

4. That environmental restrictions currently in force will not be significantly changed.

With this basic background, the utilization of fuel cells was estimated, under the assumption that the cost of fuel cells was no greater than that of the next best alternative. This involved making some assumptions, too, about how a fuel cell would actually operate in a utility system;✚ namely, that

1. The fuel cell operates primarily as a peaking unit.

2. The 15% of rated fuel cell capacity continuously on line would be operated as base load units.

3. The capital charge rate (which includes interest, amortization, and taxes) is 17%.

4. The required reserve ratio on fuel cells is 10%. This reflects the cell stack redundancy in the fuel cell section, which can maintain full power with several stacks offline, and the modularity of fuel cells.

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*Electrical World, *1975 Annual Statistical Report, 183*, p. 63 (March 15, 1975).

†*Ibid.*, p. 60

✚A utility system analysis of fuel cells is currently being performed by Public Service Electric and Gas Company and will be available in July 1976.

5. Fuel cells are sited at substations, and therefore have zero transmission line losses as opposed to about 3% losses for units at remote locations.

6. There is no credit for the spinning reserve application of fuel cells.

7. The useful life of all devices is 30 years.

8. Kilowatt-hours of delivered electricity (the benefits) are equal.

9. Fuel cells are run as peakers when gas turbines would otherwise be on line and as base load generators the rest of the time. Turbine peakers have a load factor of 11.9% (1000 hr of operation).

With these assumptions plus local fuel prices (see Appendix III), fuel cell use was estimated for 5 regions, the Northeast, Midwest, South, Southwest, and West. Whenever fuel cell costs were no greater than alternate systems, the assumption was made that they would achieve full penetration due to their many advantageous features. Several regions were divided into areas with expected winter and summer peaks because of the effect of ambient air temperature on gas turbine efficiency. In addition, Southern California was analyzed separately from the remainder of the West because of its unique characteristics. Each region was assumed to replace units in the proportion held in 1974 and to hold about the same share of the new capacity market as their share of total generation in 1975. (See Appendix IV.) Based upon this analysis (see Appendix V) fuel cell capacity would be 5.4 Gw in 1985 and 11.9 in 1990. The associated energy savings is equal to 11,100 bbl of oil per day in 1985 and 22,900 bbl in 1990. Considering the range of capital cost for fuel cells, installation could vary from 10.8 to 1.4 Gw in 1985 and from 24.6 to 1.4 Gw in 1990. The associated energy savings range from 23,000 to 2,900 bbl/day in 1985 and from 51,800 to 2,900 bbl/day in 1990. These estimates cover only the private utility intermediate peaking component of utility fuel cell demand. There are several other markets: replacement of older units, publicly-owned power and cooperatives, explicit consideration of transmission and spinning reserve credits, and the load-growth-dependent market.

The replacement generating station market is a difficult one to estimate. By assuming replacement of all units greater than 40 years of age, an estimate of 28,000 Mwe was made.* Another estimate is closer to 50,000 Mwe.† The primary condition of replacement is that new units can be purchased and operated for less than the operational costs of units currently on line. With the exception of units that either have fallen apart or are in a nonviable location, the determination of replacement is economic. At what point does new capacity operating for the same amount of time, or some combination of new capacity that covers this time period, become less costly than existing units?

Assessing the costs involves knowing the operating characteristics of each old unit, the financial shape of the utility, its load curve, expected load growth, and expected plant; such detailed analysis is clearly beyond the scope of this study. However, it can be ascertained that older units fall into three categories, intermediate, peaking, and superpeaking. The superpeaking units are very old, have high heat rates, are seldom run, but can be put on line very quickly. Examples of such units are Blount St. 1 and 2 of Madison Gas and Electric Co. These units, because of their characteristics, are replaced only upon breakdown, since for such short operating time, new capacity is not economical. The old peaking units, are one determinant of new gas turbine capacity and, therefore, were included in the earlier analysis. In the intermediate load range, fuel cells will be used where they are (1) less expensive than the existing units and (2) the lowest cost intermediate unit available. These cost factors rule out the fuel cell in all regions except the Northeast and California, since elsewhere coal-fired units are economically dominant and the number of older units in California is insignificant. Information provided by United Technologies plus examination of plant data provided by the Federal Power Commission indicate that the market involved is about 5000 Mwe. Units in this market have heat rates as low as 13,000 Btu with the highest identifiable heat rate at about 19,000 Btu. The fuel cell, if available, would economically replace units

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*United Technologies Corp.

†Temple, Barker, and Sloane, *op. cit.*, pp. II 23 - II 27.

of 13,000, or better, at the lowest point of the capital cost spectrum and units of 14,900, or better, at the highest point. The estimated range of installation, therefore, is from 3400 to 5000 Mw, with the most likely being 4500 Mw.* Associated fuel savings for 1990 ranges from 36,800 to 26,500 bbl/day, with 34,000 as the best estimate.† For 1985 the range is 18,400 to 13,300 bbl/day, with 17,000 as the best estimate.

Publicly-owned power and rural cooperatives provided 10.7% of generation and 18.3% of sales in 1972. Most of this, 8.9% of generation and 13.0% of sales, is provided by publicly-owned companies.

The great bulk of both sales and generation is provided by the largest publicly-owned utilities, as shown in Appendix VI. These systems are all large enough to be considered coequal with the private utilities, and one of them, Los Angeles Department of Water and Power, is included in the earlier analysis. Note that five of these utilities do not generate power but purchase it elsewhere, from TVA for the Tennessee utilities and from BPA in Washington; that is, they represent marketing of federal government power. Also these utilities have a much higher proportion of hydro power, with another five having hydro as their only power source. These systems are atypical and can be expected to expand slowly, if at all. Of the systems remaining the previous analysis indicates a range of fuel cell installation from 0 to 169Mw in 1985 and 0 to 494 Mw in 1990 with the best estimate being 52 Mw in 1985 and 156 Mw in 1990. Associated energy savings range from 0 to 400 bbl/day in 1985 and 0 to 1000 in 1990, with the best estimate 130 bbl/day in 1985 and 330 in 1990.

The smaller public power systems have been joining together with private companies and cooperatives to build large base load units. An example is St. George, Utah, which is purchasing 62 Mw of both Warner Valley 1

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*Based on an estimated load factor of 34% or 3000 hr per year and maintenance costs of 4.0 mills/kw-hr, which is typical for units identified as needing replacement although not operated as peaking units.

†For units above 15,000 Btu/kw-hr, it would be economical to use combined cycles, and therefore fuel savings are considerably reduced. If the units replaced are the alternative, savings range from 45,900 to 35,600 bbl/day. The units are assumed to be evenly distributed across the heat rate spectrum.

and 2 (250-Mw, coal-fired units for 1979 and 1980).* St. George currently has 7 Mw of capacity run at an annual load factor of 11%.† The cooperatives also have banded together, often at the state level, and have formed systems large enough to purchase 265 Mw of a plant. In addition there are considerable amounts of purchased power, principally from the federal government. But there will still be the need for small units. Examination of data on municipals reveals two key characteristics:

1. equipment load factors are from 20-60% and

2. purchase power is about 50% of power distribution.✚

These systems are also quite small. The principal competition for this market is the diesel generator, which is economical in small sizes. The diesel also has a reasonably low heat rate, but as its size increases so does its cost. Considering the other alternatives, and the extremely small size, less than 20 Mw for some systems, the estimated demand in this market for fuel cells is 0 to 1000 Mw by 1985 and 0 to 3000 Mw by 1990. Associated energy savings range up to 1800 bbl/day in 1985 and up to 5400 in 1990.

The question of spinning reserve and transmission line credits has received some consideration, but no clear-cut answers. Adequate assessment of the magnitude of such credits, requires a system-by-system analysis. Stopping short of this approach involves relying on estimates. Spinning reserve credit has been estimated at about $10/kw.** This credit is obviously highest where systems use high cost fuel, because it is the utilization of intermediate capacity not otherwise on line while baseload units are backed off that is responsible for this cost. Spinning reserve use results therefore in fuel savings, since backing units off raises the heat rates, albeit only marginally. There are also substantial transmission savings for fuel cells instead of remote-sited baseload units, although these savings are small versus gas turbines except in highly congested areas.

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*Electrical World Report, *op. cit,* p. 62 (March 15, 1975).

†Public Power, *1975 Directory Issue*, p. 66 (Jan/Feb 1975).

✚Data provided by United Technologies based on raw data from the Federal Power Commission.

**R. A. Fernandes, *Optimum Peak Shaving for Electric Utilities*, paper presented at IEEE Power Engineering Society, winter meeting (Jan 1975).

This savings can range from \$15 to \$75 per kw, considering that transmission capital expenditures are much higher in congested corridors, while in vacant areas, such as the southwest, land acquisition and undergrounding of lines are not yet problems.

Introducing these credits has some impact in the peaking baseload market upon units installed. The units installed by 1985 now range from 3.7 to 11.0 Gw and by 1990 from 7.4 to 25.0 Gw. Associated energy savings range from 7600 to 23,400 bbl/day in 1985 and from 15,200 to 52,600 bbl/day in 1990.

Fuel cell deployment is dramatically affected by the average national load growth. If it is 6.3%, as Appendix II suggests is possible, then fuel cell energy savings could increase by up 22,900 bbl/day in 1985 and 42,100 in 1990 and installations 12.0 Gw in 1985 and 19.2 in 1990. There are also local effects; for example, if a utility underestimates growth and load match it may experience an imminent need for capacity. The present means of meeting this need is the use of gas turbines. But since in such circumstances they would operate considerably longer than usual, often more than 2000 hours, fuel cells should consequently dominate this market. Estimations are that from 300 to 1000 Mw will be installed for this purpose by 1985 and from 600 to 2000 Mw by 1990. Associated energy savings are from 800 to 2700 bbl/day in 1985 and from 1600 to 5400 bbl/day in 1990.

Fuel cells fit into many markets due to their high reliability, good environmental features, modularity, and unique ratio of heat rate to load pattern. The total fuel cell installation for utility purposes range from 5700 to 27,800 Mw, with the base estimate at 9100 Mw for 1985. For 1990 the range is from 11,400 to 54,700 Mw, with the base estimate at 18,400 Mw. Associated energy savings range from 21,700 to 70,200 bbl/day in 1985 and from 43,300 to 142,600 bbl/day in 1990. The base estimates are 31,400 bbl/day in 1985 and 64,400 in 1990.

Examination of the economic potential of the fuel cell in a cost-benefit mode reveals sizable benefits. Although fuel cell development costs are unavailable, the base cost savings (\$9.50/kw-year) for the Northeast region were calculated for the 1980 to 2015 period, assuming a 10% discount rate. Even with this high discount rate, the cumulated benefit to society in 1975 dollars is $253,000,000.*

Integrated Energy Systems

The fuel cell is ideally suited to this market. It can be made economically at small sizes, can provide heat without loss of efficiency, and is highly reliable.† Systems to provide hot water heating and space conditioning from waste heat recovery can use as much as 80% of the energy input to a 40-kw unit and 91% to a 26-Mw unit, based upon higher heating value.‡ The waste heat available is about 54% of input with about half as water at 160°F and half as steam at temperatures as high as 330°F.** Diesel engines and gas turbines also may be used in this way, with overall efficiency similar to that of the small fuel cell. However, there is no mention of such units of less than 100 kw being used.†† The 40-kw units are estimated to cost about $500/kw installed, including heat recovery equipment, with costs per kw declining with increasing size. In the 40-kw to 100-kw range, the fuel cell will have as its competition advanced fossil fueled furnaces and conventional electric service. Currently, furnaces for this size level achieve efficiences of 65% to 80%. However, Amana Corporation has introduced a gas furnace-air conditioner with an 84% efficiency.‡‡ They plan to market the gas furnace, independent of the air conditioner, by

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*This is the highest rate used for cost-benefit studies; several other and lower rates are also in use.

†Based upon over 200,000 hr of actual operations, fuel cells should be available over 90% of the time.

‡J. M. King, A. P. Grasso, J. V. Clausi, *Final Report, Study of Fuel Cell Power Plant with Heat Recovery*, NASA 14220, p. 11 (April 24, 1975).

***Ibid.*

††G. Samuels and J. T. Meador, *Mius Technology Evaluation; Prime Movers*, ORNL (April 1974). G. M. Wolfer, *The Potential Benefit of an Advanced Integrated Utility System*, NASA (TR-X-5812) (Nov 1975). Division of Energy Bldg. Technology and Stds., HUD, *Final Environmental Statement, Application of Modular Integrated Utility Systems Technology* (Oct 1970). King et al, Final Report, *op. cit.*

‡‡T. McCrory, Amana Corp., personal communication.

1978. The high efficiency is due to a very efficient heat exchanger and low heat losses through the stack resulting from external placement. This results in a 20% energy savings according to a study performed for Amana by the Institute of Gas Technology (IGT). Assuming this type of unit, and typical electric utility system efficiency, then in a 16-unit apartment in Hartford, Connecticut, there is about a 10% energy savings from a fuel cell with heat recovery.*

The residential-commercial market from 1978-1990 requires the equivalent of 100,000 Mw of capacity.* About 40% of this market is suitable for integrated energy systems. A complete assessment of this market is not possible because of the wide range of electric prices paid by consumers and because the load level is so locationally dependent.

However, in areas with high fuel and electricity costs, some market penetration of integrated systems is expected by 1985 and more substantially by 1990. By 1985 up to 1000 Mwe of capacity in the 40-100 kw range will be installed while 500 Mwe in the 100-kw range will be in place. This capacity could increase to 3,000 Mwe in each category by 1990. In the 100-kw range, the fuel cell offers no great cost or fuel savings over its alternatives (which will have a share of this market), but it does offer considerable environmental benefits. Assuming an annual load factor of 34%, the energy savings from integrated energy systems range up to 1400 bbl/day in 1985 and 4200 in 1990.

Process Steam

In 1972, industry required 17.6 quadrillion Btu of fossil fuel.[†] About 30% of this, 5.1 quadrillion Btu, was either for process heat at no more than 330°F or for space heat.[‡] The combined demand is expected to reach 6.25 quadrillion Btu by 1985** and 6.8 by 1990, at the same rate of growth. Because fuel cells can provide up to 54% of input power as useful heat at up to 330°F without any diminution of electric output, they face, therefore, a large potential market.

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*Based upon information provided by United Technologies Corp.

†Westinghouse Electric Corporation, *The Westinghouse Templifier...A New System for Producing Process Heat*, p. 8 (Jan 1976).

‡*Ibid*, p. 8 assumes constant utilization across temperature range.

***Ibid*, p. 6.

At present, most process heat is generated either in package boilers or by backpressuring steam turbines. Package boilers operating on gas are about 75% efficient; on oil, about 70%. Back pressure units are much more capital intensive. A large unit of this type would be equivalent to about 100 Mwe (that is, converting the extracted steam to electricity). The heat rate runs about 11,500 Btu/kw-hr, because the plant operates at lower temperature and pressure and with less regeneration than central electric stations.* Smaller units do not do quite so well. There are two other, less widely used, means of providing process steam; extraction from central station steam electric plants, and from heat recovery of gas turbines. Estimations are that extraction steam can save up to 30% of the process steam user's fuel demand,† which, however, involves placing the process plant out at the power plant. Many users cannot afford such relocation, and even if they can, there are serious institutional problems. These involve regulation, long-term contracts, impacts on regional development, and provision of public services.✚ Gas turbines with waste heat recovery currently achieve 70-80% efficiences.** Given expected improvement, 80% efficiency in the 1980s seems reasonable, although the reliability of the gas turbine does not match that of the fuel cell.

One important unconventional competition to the fuel cell in this market is the templifier. The templifier employs the same principle as the heat pump, but by using a much larger compressor and working at higher temperature levels, it can produce hot water for industry. For industrial uses, a number of good heat sources are available; such as, condenser cooling water from electric power plants, cooling pond water, cooling tower water, warm water effluent from plant process, and overhead vapors from

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*S. H. Nelson, *Utilization of Low Temperature Heat from Steam-Electric Power Plants: Techniques Economics, and Institutional Issues*, unpublished doctoral dissertation, U. of Wisconsin, pp. 253 & 287 (1975).

†*Ibid*, p. 224.

✚*Ibid*, pp. 55-65 and 223-34, which see for a more complete discussion of institutional problems for matching large process steam users.

**Information provided by James Burroughs, Dow Chemical Co., based upon Dow's experience at an installation in Sudbury, Ont.

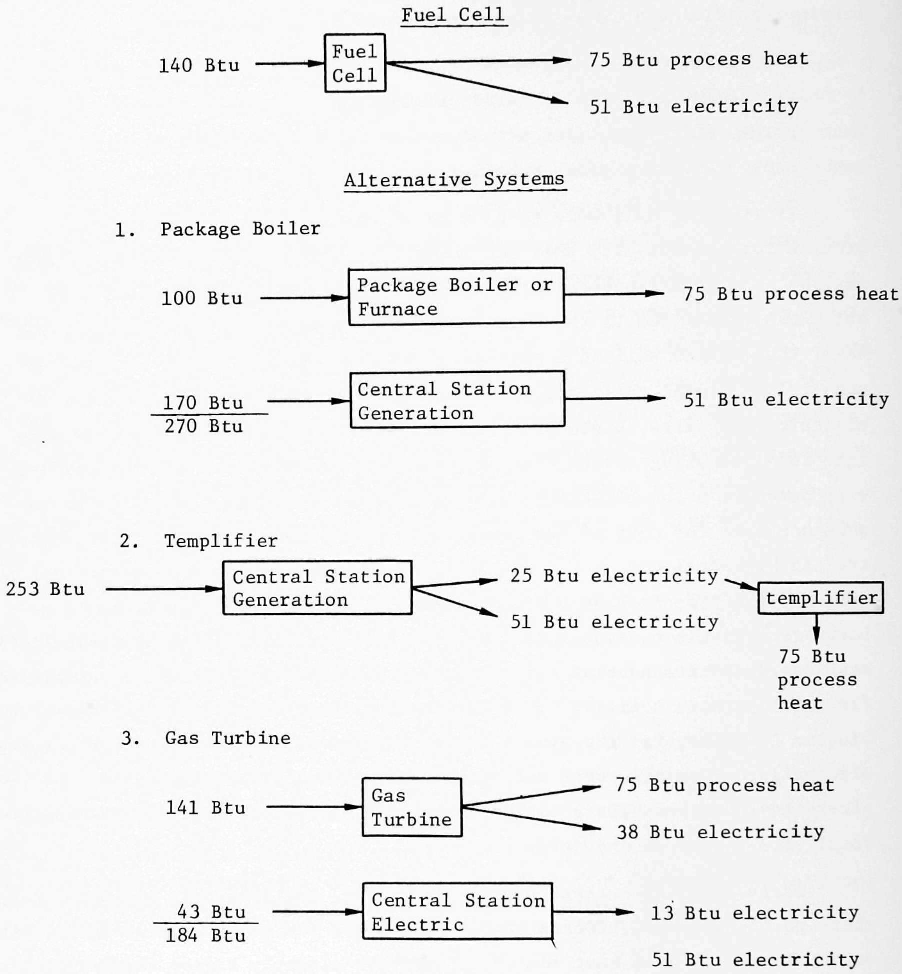
distillation processes. The templifier can heat water to 180°F from a source at 82°F and to 225°F from a source at 115°F, and still maintain a COP of 3. Its current limit is a top temperature of 230°F; however, if suitable refrigerant fluids were available this could be raised to 400°F.

The space heating component of the process heat market is provided by units similar to those in residential-commercial applications. Thus maximum current efficiency over actual operating conditions is about 75%, and hence equivalent to a package boiler.

If the fuel cell were to be used in this market, it would often provide more electricity than the industrial user needs. This possibility implies a joint arrangement with electric utilities, with the fuel cell being baseloaded due to the high (about 90%) load factor for process steam use. These units will be competitive for baseload generation for two reasons: (1) capital costs are relatively low, hardly above the cost for all electric fuel cells, since process steam provision merely involves replacing an air cooling system with a water heat exchanger and (2) the utility will perceive a low effective heat rate since it can sell steam for up to what would be the cost of the lowest cost alternative. This is particularly true in high-fuel-cost regions. The institutional problems of siting are not great to the process heat user, and seem, given past experience, to be a barrier of little consequence. The fuel cell is the lowest cost device in many cases and its nearest competitor may be either gas turbines, templifiers, or package boilers, depending on local and historical conditions. Diagram 1 illustrates the system energy savings of fuel cells versus these alternatives when all power output of the fuel cell is equalized to the alternative system. These savings range from 44 to 130 Btu per 100 Btu of fossil-fuel input to industry.

Because of these large potential savings, the fuel cell will penetrate those portions of the process heat market where the templifier is unsuitable due to lack of a good heat source or need for slightly higher temperatures; where the gas turbine is too expensive; and where package boilers are not in place or can be economically replaced. This penetration is estimated at from 7-13% of the available market in 1990 and from 3-7% by 1985, with base estimates at 10% and 5%, respectively. This leads to installation of from 4,560 to 10,550 Mwe by 1985 and from 11,760 to 22,600 Mwe 1990, DIAGRAM 1

Fuel Cell Energy Savings Compared with Alternative Power Supply Systems*



*Electricity generated at 30% efficiency. This is the recent (1974) average for generation and since efficiency has been falling for a decade, may be an overstatement, from Electrical World, March 15, 1975, 183(6), p. 58.

with respective base estimates of 7,580 and 16,800 Mwe. Assuming savings are determined by the least cost alternative, they range from 73,400 to 207,000 bbl/day in 1985, with the base estimate at 142,100. If the most energy efficient alternative is used these savings fall from 37,500 to 87,500 bbl/day, with the base estimate at 62,500. Using present technology the savings would be as large as from 110,100 to 256,800 bbl/day, with the base estimate 183,300.

For 1990 expected energy savings range from 185,000 to 415,000 bbl/day, with the base estimate at 314,000. If the most energy efficient alternative is used, these savings fall from 94,500 to 175,500 bbl/day with the base estimate 135,000. With present technology, these savings range from 277,000 to 507,500 bbl/day, with the base estimate 396,000.

Export Market

The foreign market for fuel cells is quite large. The fuel cell fits into four markets, (1) developed countries where the price differential between oil, coal, and uranium is small (e.g., Japan); (2) developed countries where environmental considerations are important; (e.g., the Netherlands); (3) developing nations attracted by the small unit size and ability to run without operating personnel; and (4) oil and gas rich nations where the low capital cost, heat rate, and unit size, as well as ability to operate without trained personnel make fuel cells attractive; (e.g., Iran). In total this market is estimated at about two times the USA utility market, with 25% of the export market being to communist bloc nations.* The export market involves both the initial equipment sale, at $170 to $270/kw manufactured cost and a resale market half again as large, based on a 30-yr operating life and $100/kw in charges for fuel cell power-section replacements.

Based upon our earlier estimates of fuel cells in the U.S. utility market, the foreign market for fuel cells ranges from 22,800 to 109,400 Mw, with the best estimate 36,800 Mw for the period 1890 to 1990. The total lifetime export potential of first-generation fuel cells to 1990 is, therefore, from $9.4 to $29.7 billion, and base cost estimate is some $11.1

*Estimate based upon personal communications with Mr. Paul Farris, United Technologies.

billion. Because there is no competition, the foreign market and the USA export market may be considered equal. That is, an export potential exists of from $9.4 to $29.7 billion. Some portion of the export market reflects capture of market shares of USA manufactured prime movers. There is also a secondary effect, through currency revaluation, that reduces other exports and increases imports. But the remainder reflects the net gain in exports. This net gain is reflected, in turn, in an increase in jobs for U.S. citizens and in taxes paid to governmental agencies. To illustrate the latter effect, take the base case and assume a 1990 cutoff date. In this case, total export value is about $7.4 billion. Assume that only half is net export, that each $30,000 yields a manufacturing job paying $12,000, that the tax rate in 1975 dollars stays constant, and that there are no associate jobs generated.* These assumptions, particularly the latter, are quite conservative. Yet the result is an average of 25,000 added jobs per year and increased federal income tax and social security revenues of $485 million (in 1975 dollars) for the decade of the 1980s.

From a benefit/cost standpoint the entire net export represents benefits. Limiting the analysis only to the decade of the 1980s, again assuming only half of exports are net, and using a 10% discount rate, current benefits in the base case are in excess of $1.25 billion.

VI. *SUMMARY AND CONCLUSIONS*

Fuel cell technology has matured to the point where a commercially competitive system can be produced, provided there is government support. With such support domestic fuel cell installation ranges from 10,300 to 39,800 Mw in 1985 and 38,200 in 1990. When compared with the best alternative, that is, the most economical advanced system available in the decade of the 1980s, associated energy savings range from 95,000 to 279,000 bbl of oil/day in 1985 and from 228,300 to 561,500 in 1990. With base estimates at 174,000 bbl/day in 1985 and 380,500 in 1990. Compared to present technology, savings range as high as 400,000 bbl/day in 1985 and 722,000 in 1990.

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*Actually there will be some associated service jobs; how many, is locationally dependent. Clearly though, none is too few.

There is also a large potential export market in which the USA will hold a monopoly. Estimated total exports range from \$9.4 to \$29.7 billion. Considering the base case, and net exports being half of total exports, then by 1990 federal government revenues will increase by greater than \$450 million (in 1975 dollars). Furthermore, discounting net exports and base estimate cost savings for the Northeast at 10%, the present value of fuel cells to the U.S. economy on a benefit basis exceeds \$1.5 billion (in 1975 dollars).

Our conclusion is that the fuel cell is a nearly mature technology offering substantial environmental benefits, sizable energy savings, and facing a large export market. Furthermore, it appears that success of the more efficient second-generation units is dependent upon successful introduction of the first-generation units. Based upon these findings government support of fuel cell development is appropriate.

APPENDIX I. CHARACTERISTICS OF ADVANCED FUEL CELL TYPES

A. Base Electrolyte Systems (low temperatures)

These systems provide very high efficiency and great flexibility on specialized fuel (hydrogen); hence they are used for spacegoing applications. It may be possible to develop a very attractive and efficient generating system based on carbonaceous fuels. Exxon and its French partner, Alsthom, are pursuing this option, but the problems are formidable, and this will doubtless be a second-generation system available perhaps in the mid to late 1980s.

B. Molten Carbonate Systems, High Temperature (500-700°C)

These systems offer very high efficiency, near 50%, and also high quality, useful reject heat that could be used for space conditioning in buildings or for process steam. They are well suited to the use of carbonaceous fuels, and provide all the benefits of flexibility, desirable environmental characteristics, etc., that are associated with other fuel cell systems. High operating temperature cells have historically caused more development difficulties than lower temperature cells, but considerable progress has been made in the last few years and commercial cells of this type may reasonably be expected to become available in the 1985-88 time period.

C. High Temperature Oxide Electrolyte Systems

These systems may yield highest efficiency of operation on a variety of fuels, perhaps in direct conjunction with coal gasification. Their very high quality reject heat would certainly be recovered, leading to overall efficiencies much greater than 50%. However, major technical problems remain to be solved, so it is exceedingly difficult to project a commercialization date with any reliability.

APPENDIX II. EFFECT OF ELECTRIC CAPACITY ON FUEL CELL DEPLOYMENT

The estimation of demand for fuel cells is very sensitive to the growth rate of electric generating capacity. If the capacity additions are 6.3% per year, which is in line with forecasts made in early 1975, then capacity in 1985 is 935 x 10^3 Mw and in 1990, 1272 x 10^3 Mw. These are about 25 and 30% greater than the estimates used in this study. However, the difference in new capacity additions during the period is startling. If the growth rate is 6.3%, then between 1981 and 1985 2.0 times the projection used will be required and 1.75 times as many megawatts for the full period. The reason behind this is that 1980 capacity is already committed, based upon growth rates of close to 7% per annum. Thus, there will be considerable excess capacity with the low projected growth rate. During the 1981-1985 period, the excess is worked off and, consequently, additions become somewhat below what they would be otherwise. Hence, there is a great difference in new capacity additions resulting from changes in the growth rate.

The possibility of the higher growth rate is not remote, for there is one factor that could compensate for others that lead to lower growth; the unavailability of natural gas. In many cases electricity is the best substitute for natural gas and, therefore, the demand for electricity is sensitive to the extent of future natural gas shortfalls, and/or the price levels that pertain when synthetic gas becomes available.

APPENDIX III. REGIONAL FUEL PRICES 1985*
(in 1975 dollars/10^6 Btu)

Northeast

Fuel Cell Fuel	2.95
Distillate Fuel Oil, Low Sulfur	2.75
Coal	1.65

Midwest

Fuel Cell Fuel	2.80
Distillate Fuel Oil, Low Sulfur	2.52
Coal	1.22

Southwest

Fuel Cell Fuel	2.74
Distillate Fuel Oil, Low Sulfur	2.56
Coal	1.15

West
(Including Southern California)

Fuel Cell Fuel	2.80
Distillate Fuel Oil, Low Sulfur	2.52
Coal	1.35 (Florida 1.65)

*Based upon *Assessment of Fuels for Power Generation by Electric Utility Fuel Cells*, A. D. Little Co. for Electric Power Research Institute, pp. 2-1 - 2-44. (Oct 1975). Assumes unit train costs are 2/3 that for a non-unit train.

APPENDIX IV. REGIONAL CAPACITY SHARES

The regions used are defined as follows: The Northeast: New England, New Jersey, Delaware, Maryland, and those portions of New York and Pennsylvania that face similar severe environmental restrictions; the Midwest: the East North Central and West North Central regions, Kentucky, and those portions of New York and Pennsylvania not severely impacted environmentally; the South: those states east of the Mississippi not included above; the Southwest: Texas, Arkansas, Oklahoma, and Louisiana; and the West: the remaining states except Southern California, which is a region of its own.

With these definitions, the share of the U.S. private electric generating capacity in 1972 was:*

Regional Generation Shares (in %)†

Northeast	13.1
Midwest	34.2
South	25.4
Southwest	15.6
West	8.6
Southern California	4.3

The regional shares for the replacement market (including internal combustion units as a separate entry) are:

Replacement Market Regional Shares (in %)✚

Northeast	25.4
Midwest	28.8
South	22.5
Southwest	3.5
West	6.8
Southern California	1.8
Internal Combustion	11.3

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*Exceeds 100% due to inclusion of publicly-owned utilities in Southern Calif.

†Based upon *Steam Electric Plant Factors 1973*, National Coal Assn., pp. 53-54, (1974), and *Electric Power Statistics*, FPC (Jan 1972).

✚Based upon Electric World Report, *op. cit.*, p. 63 (March 15, 1975).

APPENDIX V. ANNUAL GENERATING COST PER KW BASED ON 1987 INSTALLATION

SOUTHERN CALIFORNIA

Southern California, or more properly the Los Angeles basin, faces a unique electric generating condition. Because of the severe environmental problems, electric generating stations are NOX dispatched. Thus, if a unit with low NOX is placed on line, it must be brought up to full load as fast as practicable. Fuel cells in this market would be competing primarily in the intermediate market, since they would have to be either all on or all off. The competition would be combined-cycle units. These units must be remotely located at a 3% energy penalty and about a $15 transmission line capital cost.* Estimated load factor is about 45%, with annual hours of operation at 4000 hours. Because they are run from a cold start straight up to full load, fuel cell heat rates would probably be about 9300 Btu/kw-hr, the end-of-life design conditions.

The situation in Southern California is quite unstable. There is no coal-fired electric station in the state. California has been able to build coal plants in neighboring states, but this policy is being viewed with increasing disfavor by the host states. A nuclear referendum is currently on the ballot. If it passes, the only options are, geothermal, solar, and oil-powered generation. At least, initially, the bulk of the generation would be oil based, and the fuel cell because of its sitability would probably dominate this market.

In the following cost comparison, the superior reliability of fuel cells is accounted for.†

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*Conversations with Dr. Ira Thierer, Southern California Edison.

†See Table 1. This is done by requiring some gas turbines to operate to equalize electricity production.

Southern California Annual
*Cost Per kw, Assuming 1987 Installation**

Fuel Cells

Capital Cost	=	\$230/kw x 0.17 capital charge rate	=	\$ 39.10
Fuel Cost	=	9300 Btu/kw-hr x 4000 kw-hr x 3.08 10^6 Btu	=	114.58
Operating and Maintenance Cost	=	3.0 mills/kw-hr x 4000 kw-hr + \$0.26	=	12.26
		Total Annual Cost		\$165.94

Alternative Power Generation

Combined Cycle Plant

Capital Cost	=	\$210/kw + \$15/kw transmission x 1.03 x 0.17	=	\$ 39.40
Gas Turbine Peaking (Units required to equalize system reliability)	=	\$140/kw x 1.03 x .17 x 0.1	=	2.46

Fuel Cost

Combined Cycle	=	9000 Btu/kw-hr x 1.03 x 3160 kw-hr x \$2.74/10^6 Btu	=	80.21
Gas Turbine (operation required due to differences in reliability)	=	13000 Btu/kw-hr x 1.03 x 840 kw-hr x \$2.74/10^6 Btu	=	38.82

Operating and Maintenance Cost

Combined Cycle	=	\$0.90 + 3160 kw-hr x 3.7 mills/kw-hr	=	\$ 12.59
Gas Turbine	=	\$2.26 + 840 kw-hr x 5.0 mills/kw-hr	=	4.22
		Total Alternative Cost	=	\$177.70

Fuel Cell Saving = \$ 11.76

Break-even Capital Cost = \$299.00/kw

*The fuel cost used is levelized for the 30-year period. Base case fuel cell cost is \$230/kw.

NORTHEAST

Fuel Cells

Capital Cost	=	\$230/kw x 0.17 capital charge rate	=	\$ 39.10
Fuel Cost	=	9000 Btu/kw-hr x 2061 kw-hr x \$3.30/10^6 Btu	=	61.20
Operating and Maintenance Cost	=	3.0 mills/kw-hr x 2061 kw-hr + \$0.26	=	6.44
		Total Annual Cost	=	\$105.74

Alternative Power Generation

Because of environmental constraints the baseload alternative is an oil-fired unit.

Capital Cost

Oil Baseload Unit	=	\$330 x 1.03 x 0.15 kw x 0.17	=	\$ 8.67
Gas Turbine Peaking	=	\$140 x 1.03 x 0.95 kw x 0.17	=	23.27

Fuel Cost

Oil Baseload Unit	=	9800 Btu/kw-hr x 1.03 x 1060 kw-hr x \$3.08/10^6 Btu	=	32.96
Gas Turbine	=	12000 Btu/kw-hr x 1.03 x 1001 kw-hr x \$3.08/10^6 Btu	=	41.00

Operating and Maintenance Cost

Oil Baseload	=	\$3.60 + .35 mills/kw-hr x 1060	=	3.97
Gas Turbine	=	\$0.26 + 5.0 mills/kw-hr x 1001	=	5.27
		Total Annual Cost	=	\$115.24

Fuel Cell Saving = \$ 9.50

Break-even Capital Cost = \$286.00/kw

MIDWEST

Fuel Cell

Capital Cost (see Northeast)		=	\$ 39.10
Fuel Cost	= 9000 Btu/kw-hr x 2061 kw-hr x $3.14/10^6$ Btu	=	58.24
Operating and Maintenance Cost (see Northeast)		=	6.44
	Total Annual Cost	=	\$103.78

Alternative Power Generation

Capital Cost

Coal Baseload	= \$55/kw x 1.03 x .15 kw x 0.17	=	\$ 13.13
Gas Turbine	(see Northeast)	=	23.27

Fuel Cost

Coal Baseload	= 10200 Btu/kw-hr x 1.03 x 1060 kw-hr x $\$1.35/10^6$ Btu	=	15.03
Gas Turbine	= 12000 Btu/kw-hr x 1.03 x 1060 kw-hr x $\$2.82/10^6$ Btu	=	34.98

Operating and Maintenance Cost

Coal Baseload	= \$4.0 + 1.0 mills/kw-hr x 1060/kw-hr	=	5.06
Gas Turbine	(see Northeast)	=	5.31
	Total Annual Cost	=	\$ 96.78

Fuel Cell Saving = \$ 6.90

Break-even Capital Cost = \$189.00/kw

SOUTHWEST

Fuel Cell

Capital Cost (see Northeast)	=	\$ 39.10
Fuel Cost = 9000 Btu/kw-hr x 2061 kw-hr x $\$3.07/10^6$ Btu	=	56.95
Operating and Maintenance Cost (see Northeast)	=	6.44
Total Annual Cost	=	\$102.49

Alternative Power Generation

Capital Cost

Coal Baseload (see Midwest)	=	\$ 13.13
Gas Turbine (see Northeast)	=	23.27

Fuel Cost

Coal Baseload	=	10,200 Btu/kw-hr x 1.03 x 1060 x $\$1.27/10^6$ Btu	=	14.14
Summer Peak Gas Turbine*	=	13,000 Btu/kw-hr x 1.03 x 1001 x $\$2.87/10^6$ Btu	=	38.46
Winter Peak Gas Turbine	=	12,000 Btu/kw-hr x 1.03 x 1001 x $\$2.87/10^6$ Btu	=	35.50

Operating and Maintenance Cost

Coal Baseload (see Midwest)	=	5.06
Gas Turbine (see Northeast)	=	5.31
Winter Peak Total Annual Cost	=	\$ 96.41
Summer Peak Total Annual Cost	=	\$ 99.37

Winter Peak Fuel Cell Saving	=	-\$ 6.08
Summer Peak Fuel Cell Saving	=	-\$ 3.12
Winter Peak Break-even Capital Cost	=	\$194.00/kw
Summer Peak Break-even Capital Cost	=	\$212.00/kw

*Texas, Louisiana, and Oklahoma, based upon *Electricity Market Fact Sheets by States, 1970* (refers to time-of-system peak), J. G. Asbury and R. F. Talkie, Argonne National Laboratory (Jan 1976).

WEST

Fuel Cell

Capital Cost (see Northeast)	=	\$ 39.10
Fuel Cost = 9000 Btu/kw-hr x 2061 kw-hr x \$3.08/10^6 Btu	=	57.15
Operating and Maintenance Cost (see Northeast)	=	6.44
Total Annual Cost	=	\$102.67

Alternative Power Generation

Capital Cost

Coal Baseload (see Midwest)	=	\$ 13.13
Gas Turbine (see Northeast)	=	23.27

Fuel Cost

Coal Baseload	=	10,200 Btu/kw-hr x 1.03 x 1060 x \$1.17/10^6 Btu	=	13.03
Winter Peak Gas Turbine	=	12,000 Btu/kw-hr x 1.03 x 1001 x \$2.64/10^6 Btu	=	32.66
Summer Peak Gas Turbine*	=	13,000 Btu/kw-hr x 1.03 x 1000 x \$2.69/10^6 Btu	=	35.88

Operating and Maintenance Cost

Coal Baseload (see Midwest)	=	5.06
Gas Turbine (see Northeast)	=	5.31
Winter Peak Total Annual Cost	=	\$ 93.43
Summer Peak Total Annual Cost	=	\$ 96.15

Winter Peak Fuel Cell Saving	=	-\$ 9.24
Summer Peak Fuel Cell Saving	=	-\$ 6.52
Winter Peak Break-even Capital Cost	=	\$176/kw
Summer Peak Break-even Capital Cost	=	\$192/kw

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*Arizona, based upon Asbury and Talkie, *op. cit.*

SOUTH

Fuel Cell

Capital Cost (see Northeast)	=	\$ 39.10
Fuel Cost = 9000 Btu/kw-hr x \$314/10^6 Btu	=	58.27
Operating and Maintenance Cost (see Northeast)	=	6.44
Total Annual Cost	=	\$103.75

Alternative Power Generation

Capital Cost

Coal Baseload (see Midwest)	=	\$ 13.13
Gas Turbine (see Northeast)	=	23.27

Fuel Cost

Coal Baseload	= 10,200 Btu/kw-hr x 1.03 x 1060 x \$1.51/10^6 Btu	=	16.81
Gas Turbine			
Mid South Winter Peak	= 12,000 Btu/kw-hr x 1.03 x 1001 x \$2.82/10^6 Btu	=	34.98
Deep South Summer Peak	= 13,000 Btu/kw-hr x 1.03 x 1001 x \$2.82/10^6 Btu	=	37.88

Operating and Maintenance Cost

Coal Baseload (see Midwest)	=	5.06
Gas Turbine (see Northeast)	=	3.31
Total Annual Cost (Mid South)	=	\$ 98.56
Total Annual Cost (Deep South)	=	\$101.46

Fuel Cell Saving (Mid South) = -\$ 5.22
(Deep South) = -\$ 2.32

Break-even Capital Cost (Mid South) = \$200/kw
(Deep South) = \$217/kw

Due to higher coal prices in Florida (\$1.85/10^6 Btu levelized), the fuel cell has about a \$3.00 edge in that market, which is 4.5% of the national market, for the base case cost of \$230/kw.

APPENDIX VI. GENERATING CAPACITY OF 20 LARGE LOCAL PUBLICLY-OWNED UTILITY SYSTEMS 1972***

		Mwe	Mwe Hydro
1.	Utility Power Authority, State of New York	4200	4200
2.	Department of Water & Power, Los Angeles, California	4806	-
3.	Puerto Rico Water Resources Authority	3048	-
4.	Grant County Public Utility District, Ephrata, Washington	1620	1620
5.	Chelan County Public Utility District, Wenatchee, Washington	1592	1592
6.	Light, Gas, and Water Division, Memphis, Tennessee	-	-
7.	Department of Lighting, Seattle, Washington	1528	1466
8.	Nashville Electric Service, Nashville, Tennessee	-	-
9.	Salt River Project, Phoenix, Arizona	1906	241
10.	Nebraska Public Power District, Columbus, Nebraska	1584	133
11.	Public Service Board, San Antonio, Texas	1778	-
12.	Electric Power Board, Chattanooga, Tennessee	-	-
13.	Jacksonville Electric Authority	1343	-
14.	Omaha Public Power District, Omaha, Nebraska	1334	-
15.	Douglas County Public Utility District, E. Wenatchee, Washington	774	774
16.	Sacramento Municipal Utility District, Sacramento, California	649	649
17.	Snohomish County Public Utility District, Everett, Washington	-	-
18.	Department of Public Utilities Tacoma, Washington	718	659
19.	Knoxville Utility Board, Knoxville, Tennessee	-	-
20.	Water, Light, and Power Department, Austin, Texas	995	-
Total Capacity		26,541	11,334

67.2% systems capacity for publicly-owned systems

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*Each utility listed is in the top 15 in customers served, kw-hr sales, electrical revenue or net electric plant.

**Public Power, pp. 29-70 (Jan-Feb 1975).

MWH SALES OF 20 LARGE PUBLICLY-OWNED UTILITY SYSTEMS TO ULTIMATE CUSTOMERS
1972 Mwh Sales (ooo omitted)*

1.	Power Authority of the State of New York	22,678
2.	Department of Water & Power, Los Angeles, California	16,975
3.	Grant County Public Utility District, Ephrata, Washington	9,786
4.	Puerto Rico Water Resources Authority	9,084
5.	Chelan County Public Utility District, Wenatchee, Wash.	7,835
6.	Light, Gas, and Water Division, Memphis, Tennessee	7,545
7.	Department of Lighting, Seattle, Washington	6,526
8.	Nashville Electric Service, Nashville, Tennessee	6,245
9.	Salt River Project, Phoenix, Arizona	6,035
10.	Nebraska Public Power District, Columbus, Nebraska	5,270
11.	Public Service Board, San Antonio, Texas	5,027
12.	Electric Power Board, Chattanooga, Tennessee	4,719
13.	Jacksonville Electric Authority, Jacksonville, Florida	4,514
14.	Omaha Public Power District, Omaha, Nebraska	4,319
15.	Douglas County Public Utility District, E. Wenatchee, Wash.	4,160
16.	Sacramento Municipal Utility District, Sacramento, California	4,102
17.	Snohomish County Public Utility District, Everett, Wash.	2,966
18.	Department of Public Utilities, Tacoma, Washington	4,066
19.	Knoxville Utilities Board, Knoxville, Tennessee	3,114
20.	Water, Light, and Power Department, Austin, Texas	2,568
Total Sales		137,534

75.5% of sales of publicly-owned systems

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*For utilities 16-20 line losses are estimated, based on those of the most comparable system.

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